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GRANITIC SOIL POTASSIUM AND
ITS RELATION TO THE PRO-
DUCTION OF HAY



By B. E. CURRY and T. O. SMITH

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GRANITIC SOIL POTASSIUM AND ITS RELATION TO THE PRODUCTION OF HAY*

BY B. E. CURRY AND T. O. SMITH

Until recent years, the theory of soil fertilization has rested almost entirely upon the practice of adding plant food or amendments to the soil in the form of fertilizers and manures for the purpose of increasing production. In practice, the ultimate aim is to obtain an increased production at a profit. With our present knowledge of soil management, tillage, and fertilization, it is a simple proposition to increase yields, but it is not as simple a proposition to secure profitable increased yields. It is doubtful, from a practical point of view, whether the maximum yield is the most profitable.

The practice of applying fertilizers is followed because the amount of plant food in the soil is considered insufficient or unavailable for the needs of the crop. For special cases, as in market gardening and greenhouse culture, where high-priced crops are grown, the relatively small cost of fertilizers becomes almost negligible. In other crops, such as the average farmer grows, the difference of a few dollars makes the difference between profit and loss. The aggregate of values of farm crops is largely derived from the ordinary crops grown under ordinary conditions.

In New Hampshire, one of the large cash crops is hay. The farms have generally been allowed to run down and become unproductive. The soil is apparently as good as it ever was, but through neglect, production has decreased. A larger acreage is devoted to grass than to any other crop. This condition has become established through the natural adaptability of the soil to grass culture, and through certain economic factors due to location and labor problems. The heavy horse and ox power once so common on New Hampshire farms is now largely a condition of the past. Partly because of this, the land does not get the cultivation it once had. Commercial fertilizers have in part

* A continuation of the work reported at the Eighth International Congress of Applied Chemistry, Vol. XV, page 51.

been substituted for tillage in order to maintain production under the conditions of lessened cultivation.

Many general observations lead one to believe that the present method of using commercial fertilizers in the production of hay is often unprofitable. There seems to be very little doubt that, in the common use of fertilizers, a very large proportion of the plant food added is never converted into profitable plant products. It is doubtful if the use of commercial fertilizers can long be substituted for tillage and other important soil factors which enter into profitable plant production.

The soils of New Hampshire are extremely varied in character and are, for the most part, of granitic origin. Almost any type may be found between the limits of sand and pure boulder clay. The sands in many instances are rich in feldspathic and other minerals. Many of the types have been considerably washed while others seem to have been formed in place. Areas of limestone soil are very limited and are found in only a few sections.

In connection with the use of commercial fertilizers in the production of grass, some very interesting facts have been found. Many of the grass fertilizers carry a large amount of potassium. Also the tillable soils are on the average very rich in potassium. Those soils which are relatively poor in potassium contain large amounts in the aggregate. Some of the boulder clay soils contain as high as 3% potassium oxide. Assuming that an acre foot of soil weighs three million pounds, such a soil would contain forty-five tons potassium oxide per acre. Some of the medium clay soils carry about 2% potassium oxide while the light soils carry still less. Some very sandy soils have been found which contain as much as 1% potassium oxide. Such soils carry a considerable amount of mineral in connection with the sand.

With these large quantities of potassium oxide present in the soil, there came the question of the use of potassium in commercial fertilizers. Could not the soil, under proper tillage conditions, supply enough potassium for the needs of the crop without the addition of potassium from artificial sources? It is a fact that where potassium is added in comparatively large quantities as a fertilizer constituent, that this amount is very insignificant when compared with the amount of potassium present in the soil under natural conditions. To illustrate: sixty pounds of potassium

oxide is higher than the average application per acre. In a soil which carries 2% potassium oxide, the amount per acre foot totals sixty thousand pounds. In comparison with sixty thousand pounds sixty becomes a very small quantity. Under such conditions, one pound is added to one thousand pounds already present.

The soils on which the experiments reported in this work were made represent fairly well the hay soils in this state. They were formed from granitic rocks by the grinding action of the glaciers and subsequent weathering processes. These soils usually lie upon a foundation of ledge in the uplands and upon beds of boulder clay in the lowlands. In some of the lowlands, the boulder clay comes near the surface and forms the subsoil and at one time constituted the surface soil.

Early in the history of the Experiment Station, several analyses were made of the heavy clay soils on the college farm which showed 1% of potassium oxide soluble in strong acid. This would be equivalent to thirty thousand pounds of potassium oxide in the upper foot of an acre of soil. This enormous amount of potassium was believed to be unavailable to plants, or else so slowly soluble as to be of little use to the growing crop.

Observations on the hay crops grown on these soils for several successive years showed that the grass plant was able to make use of the soil potassium. The problem presented by these observations was the determination of the rate of availability of the natural potassium compounds and whether this rate was sufficiently rapid to produce a large crop without exhausting the soluble compounds.

Clay soils formed from granitic rocks are naturally rich in compounds of potassium because they are principally made by the pulverizing of feldspar which is one of the constituents of granite, and richest in potassium of any of the common minerals. Feldspar may carry from 6 to 14% potassium oxide. Sandy soils, on the other hand, are largely formed from quartz, another mineral in granite which is harder than feldspar, does not pulverize as easily and contains no potassium. However, some of our so-called sandy soils are mixed with large quantities of minerals which carry large amounts of feldspathic material and some clay, and, on the whole, contain considerable amounts of potassium. The intervalle sands are usually very poor in mineral constituents.

A chemical analysis of the soil is of little use when studied alone for showing the needs or capacity of that soil. However, a chemical analysis may be valuable when taken in connection with field experiments and analyses of crops. Preliminary observations showed a considerable range in the amounts of potassium oxide in soils which were producing good yields of hay and which were known to be good hay soils. The range varied from about 1% to about 3½% potassium oxide. Average results show that samples taken from heavy clay lowland soils may carry 3.00% K₂O. The range on these soils varies from 2.21% to 3.96%. Upland soils may average 2.24% with a range from 2.05% to 2.75%. Lighter soils will carry less.

No proportional relation could be established between the yields and the percentage of potash in the crop. The total amount of potassium removed appeared to be directly proportional to the amount of hay produced.

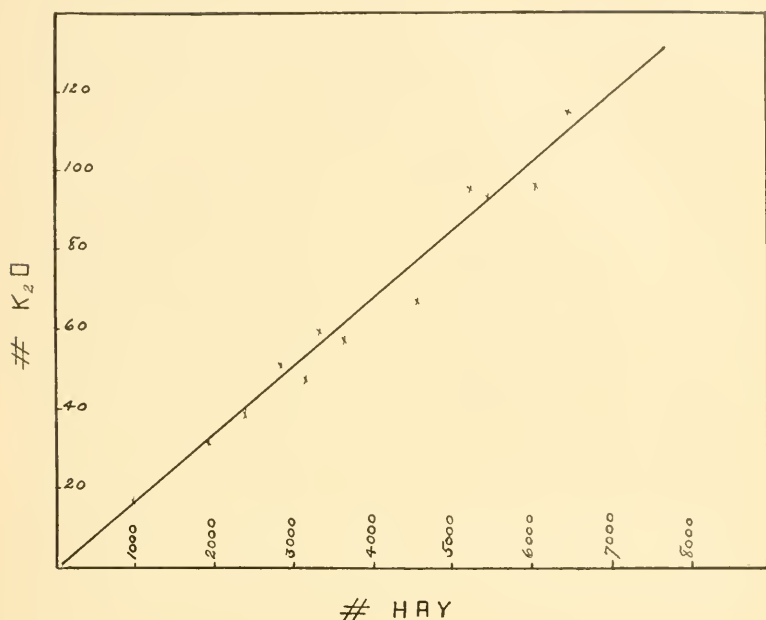
The data given in Table I shows the yield and the amount of potassium oxide in the crop.

TABLE I

No.	Yield per acre	Per cent. K ₂ O	Lbs. K ₂ O
1	945	1.80	17
2	1875	1.77	32
3	2344	1.67	39
4	2818	1.87	52
5	3088	1.54	48
6	3268	1.85	60
7	3616	1.61	58
8	4504	1.51	68
9	5174	1.86	96
10	5412	1.73	94
11	6010	1.62	97
12	6374	1.81	115

Figure 1 shows graphically the relation between the amount of hay produced and the potassium oxide it contained.

FIG 1



The plots from which these data were secured were not fertilized and were located on heavy clay soil. Moisture conditions also were very favorable as the large yields show. Later data indicate that only under the most favorable conditions will the crop absorb such a high per cent. of potassium oxide. The relation between yields of hay and the amounts of potassium oxide removed shows clearly that, as yields increased, the potassium oxide taken up increased proportionately. These observations cover a fairly wide range of yields and show that these soils can supply enough soluble potassium to produce good crops.

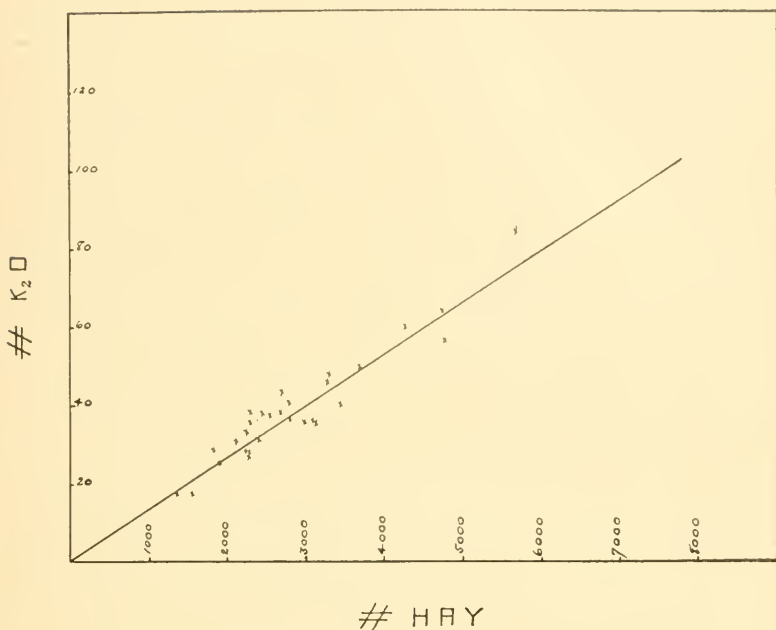
When the observations are extended to soils of lighter character, where no fertilizers have been used, the amount of potassium removed by the crop is still proportional to the yield. However, the relative amount removed is not so great as is removed from the heavier soils. The data in Table II show the yield, per cent. of potassium oxide and the amount of potassium oxide removed.

TABLE II

No.	Yield per acre	Per cent. K ₂ O	Lbs. K ₂ O
1	1365	1.25	17.06
2	1540	1.12	17.25
3	1846	1.54	28.43
4	1921	1.31	25.16
5	1978	1.47	29.08
6	2134	1.43	30.50
7	2246	1.24	27.85
8	2257	1.46	32.95
9	2275	1.16	26.39
10	2274	1.21	27.50
11	2306	1.53	35.28
12	2310	1.65	38.12
13	2380	1.31	31.17
14	2450	1.54	37.73
15	2542	1.46	37.10
16	2703	1.40	37.84
17	2724	1.59	43.20
18	2809	1.29	36.24
19	2814	1.44	40.52
20	3010	1.19	35.82
21	3119	1.14	35.56
22	3150	1.12	35.28
23	3282	1.40	45.95
24	3322	1.44	47.83
25	3465	1.20	40.38
26	3716	1.34	49.79
27	4312	1.39	59.92
28	4770	1.34	63.92
29	4802	1.18	56.66
30	5717	1.47	84.04

Figure 2 shows graphically the relation between the yield and the amount of potassium removed.

FIG 2



The position of this line is below the corresponding line in Figure 1 and it may also be somewhat influenced by the fact that moisture conditions affected the yield and possibly the composition of the crop.

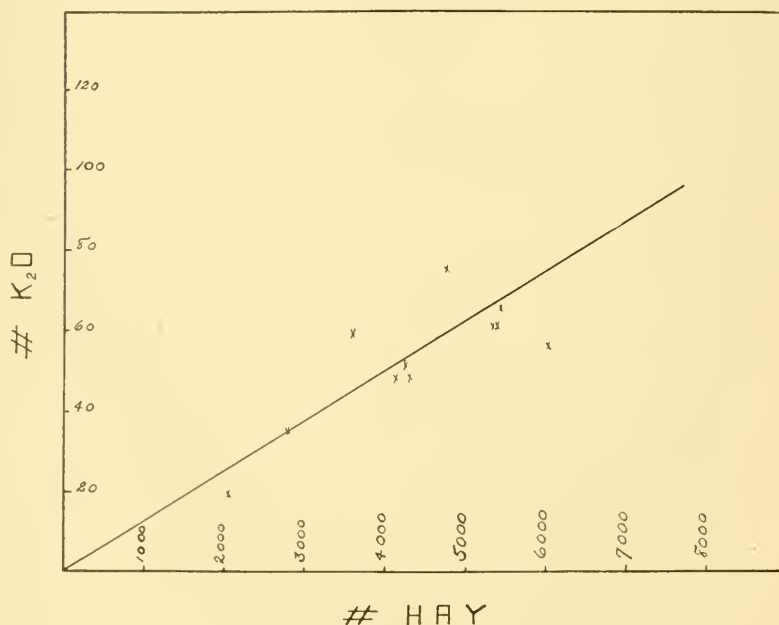
In order to show the effect of nitrogenous fertilizers on the yield and potassium content of the crop, data have been obtained from plots fertilized with nitrate of soda. Table III shows the yield, the per cent. of potassium oxide and the amount of potassium oxide removed.

TABLE III

No.	Yield per acre	Per cent. K_2O	Lbs. K_2O
1	2065	.95	19.62
2	2828	1.26	35.63
3	3636	1.65	59.99
4	4148	1.18	48.95
5	4270	1.22	52.09
6	4318	1.14	49.22
7	4766	1.60	76.26
8	5390	1.15	61.98
9	5398	1.15	62.07
10	5460	1.22	66.61
11	6055	.94	56.92

This data is shown graphically in Figure 3.

FIG 3



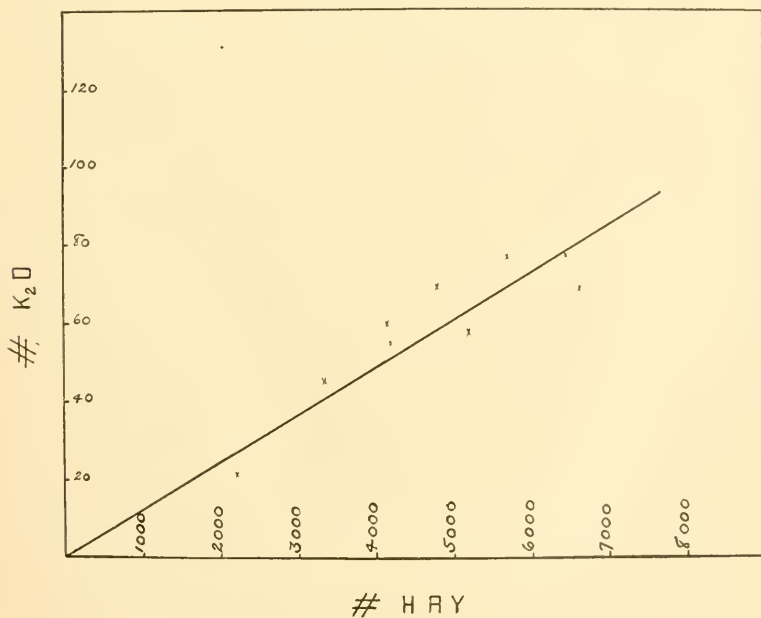
The data in the following table shows the yield and potassium content of hay grown on plots fertilized with nitrate of soda and acid phosphate.

TABLE IV

No.	Yield per acre	Per cent. K_2O	Lbs. K_2O
1	2205	.97	21.39
2	3332	1.36	45.32
3	4165	1.45	60.39
4	4200	1.32	55.44
5	4830	1.45	70.03
6	5212	1.12	58.37
7	5720	1.35	77.22
8	6475	1.20	77.70
9	6650	1.04	69.16

This data is shown graphically in Figure 4.

FIG. 4



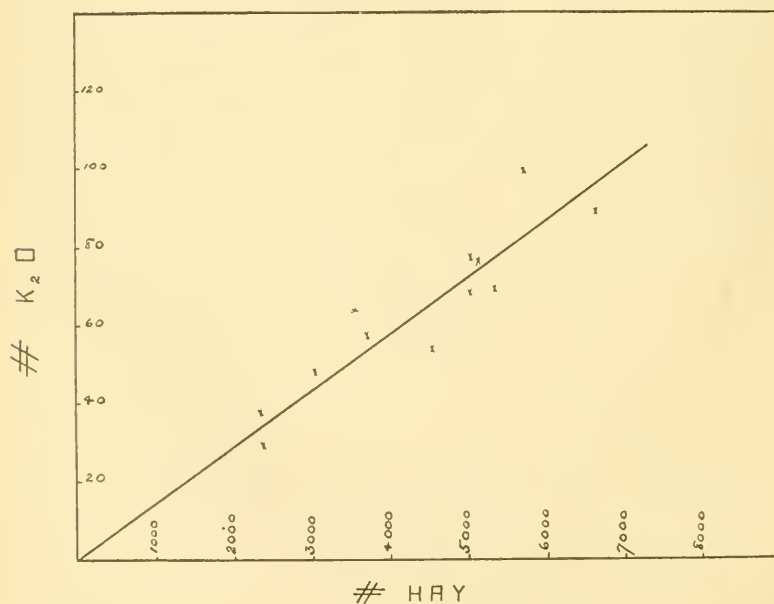
The data in the following table shows the yield and potassium content of hay grown on plots fertilized with nitrate of soda and sulphate of potash.

TABLE V

No.	Yield per acre	Per cent. K_2O	Lbs. K_2O
1	2360	1.60	37.76
2	2380	1.18	28.08
3	3042	1.59	48.37
4	3722	1.55	57.69
5	4550	1.19	54.15
6	5040	1.54	77.61
7	5048	1.36	68.65
8	5145	1.49	76.66
9	5355	1.30	69.62
10	5775	1.73	99.91
11	6650	1.34	89.11

The data in Table V is shown graphically in Figure 5.

FIG 5



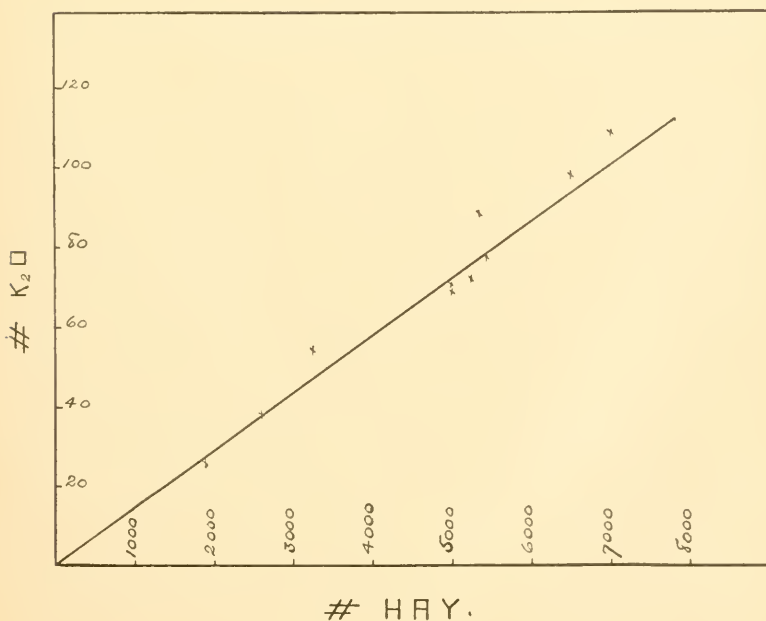
The data in the following table shows the yield and potassium content of hay grown on plots fertilized with nitrate of soda, acid phosphate and sulphate of potash.

TABLE VI

No.	Yield per acre	Per cent. K_2O	Lbs. K_2O
1	1925	1.36	26.18
2	2614	1.48	38.69
3	3268	1.68	54.92
4	4900	1.05	51.45
5	5005	1.42	71.07
6	5012	1.38	69.16
7	5250	1.38	72.45
8	5355	1.66	88.89
9	5425	1.45	78.66
10	6545	1.51	98.83
11	7000	1.56	109.20

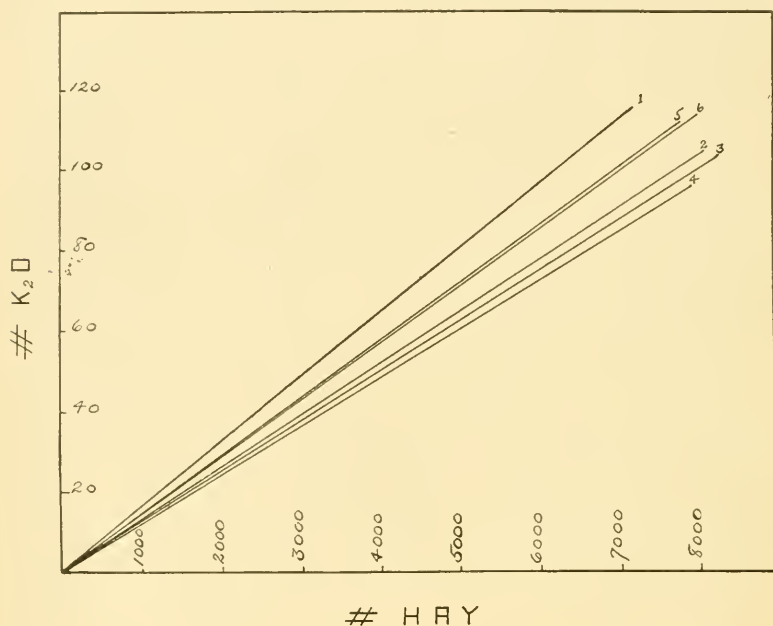
The data in Table VI is represented graphically in Figure 6.

FIG. 6



In order to show in a comparative way the relative amount of potassium oxide taken up by the crop under different conditions, all of the lines of the preceding figures have been plotted together in Figure 7.

FIG 7



The number of the lines in this figure correspond to the number of the respective figures from which they were taken.

In connection with the use of fertilizers on soils and their effect on the composition of the crop, it is interesting to note what becomes of the fertilizers when they are applied to the soils. When dilute solutions containing potassium salts are percolated through columns of soil, the potassium is removed from solution and changed into a more or less insoluble form. If the salt is the nitrate, chloride, or sulphate, the acid radical remains in solution as the acid radical of some new salt. If the salt is a phosphate, both the acid and basic radicals are left behind and no new salt appears in the percolate as in the other cases. The same conditions hold when potassium salts come in contact with

soils in other ways. In order to show these reactions, five fairly representative soils were selected. Their analyses follow:

TABLE VII

Soil No.	1	2	3	4	5
Loss on Ignition	2.660	5.333	5.830	4.905	7.260
Moisture	.770	1.419	0.516	.908	1.681
SiO ₂	81.050	74.090	72.020	71.850	62.340
P ₂ O ₅	.070	.084	.073	.085	.089
F ₂ O ₃	1.448	2.856	2.896	2.688	3.428
Al ₂ O ₃	9.017	12.195	13.446	14.702	18.638
CaO	.756	.722	.764	.806	.956
K ₂ O	1.630	1.730	1.910	2.470	2.990
N	.081	.186	.290	.148	.257
Total	97.482	98.615	98.745	98.462	97.609
Na, Mg, etc., not determined	2.518	1.385	1.255	1.538	2.391

Sample No. 1 is a light sandy soil, No. 2, a light clay loam, No. 3, a sandy loam, No. 4, a heavy clay loam, and No. 5, a heavy boulder clay.

In order to show how fertilizers behave when they come in contact with soils, solutions of various salts, of known strengths, were percolated through columns of soils, the rate of percolation being controlled by means of capillary tubes and the height of the water level in the containing vessel. The flow was adjusted at the rate of about 90 cc. per 24 hours. The strength of the solutions was made uniform on the basis of the potassium equivalent. The changes effected in the passage through the soil were determined by studying the percolate. In this way, it was possible to determine what had been taken from and what had been added to the original solution.

All the chloride, nitrate and sulfate radicals were left in solution; for that reason these radicals were not considered further.

Excepting phosphates, all the solutions were destructive in respect to the soil itself; but, in the process of destruction, new bases were substituted for the ones removed.

The results obtained, when potassium chloride solution, containing the equivalent of 0.35 grams potassium oxide per liter, is percolated through 500 gms. of soil, are shown in the following table:

TABLE VIII

No. of Soil.	Grams K ₂ O removed from first 300 cc.	Grams K ₂ O removed from third 300 cc.	Grams K ₂ O removed from fifth 300 cc.	Grams K ₂ O removed from seventh 300 cc.	Grams K ₂ O removed from ninth 300 cc.	Grams K ₂ O removed from eleventh 300 cc.	Grams K ₂ O removed from first 3600 cc. (Approx.)
1	.0152	.0078	.0050	.0030	.0020	.0018	.0609
2	.0193	.0096	.0068	.0064	.0040	.0024	.0861
3	.0205	.0089	.0074	.0061	.0058	.0032	.0928
4	.0250	.0104	.0080	.0078	.0058	.0028	.1057
5	.0280	.0139	.0090	.0080	.0067	.0043	.1305

While lime, magnesium and small amounts of iron, aluminum, etc., become soluble, a certain amount of potassium is removed from solution and retained in the soil. The data show that some of the soils remove a large part of the potassium from the first portions of the percolate. As more solution is percolated through the soils, smaller quantities of potassium are retained. While these soils contain naturally large amounts of potassium, they remove additional amounts from solution. The soils, richer in clay and also in potassium, retain larger amounts than the lighter soils which are relatively poorer in clay and potassium.

When the soil which has taken up potassium is washed continuously with water, more and more of the potassium goes into solution. However, it is very difficult to recover all the potassium after it is once taken up by the soil. When potassium is supplied as a fertilizer, it forms a more concentrated soil solution during the time that these adjustments are taking place. During this time, the plant should take up an excess of potassium

In order to show in a different way the behavior of soils toward potassium salts, known amounts of potassium chloride in solution were added to these soils and the moisture content brought up to 20 % by the addition of water. The samples were thoroughly mixed, placed in sealed jars, and allowed to stand for several weeks. They were then shaken with water and the amount of soluble potassium determined by the chloroplatinate method. The results follow:

TABLE IX

No. of Soil	Grams K ₂ O as KCl per Kg. soil	Total grams K ₂ O recovered	Total grams K ₂ O retained in the soil
1	.9354	.7012	.2342
	.6236	.4471	.1765
	.3118	.2024	.1094
	.1559	.0072	.0587
2	.9354	.6173	.3181
	.6236	.3872	.2364
	.3118	.1871	.1237
	.1559	.0841	.0718
3	.9354	.5517	.3837
	.6236	.3460	.2776
	.3118	.1724	.1394
	.1559	.0709	.0850
4	.9354	.4400	.4954
	.6236	.3101	.3135
	.3118	.1240	.1878
	.1559	.0561	.0998
5	.9354	.3243	.6111
	.6236	.2712	.3524
	.3118	.0779	.2339
	.1559	.0437	.1122

This data shows that large amounts of potassium are taken up and held by the soils. Also, that the amount of potassium so held increases with increase in the clay content of the soil. If di-potassium phosphate is substituted for potassium chloride under the above conditions, the following results are observed:

TABLE X

No. of Soil	Grams K_2O as K_2HPO_4 per Kg. of soil	Total grams soil K_2O recovered	Total grams K_2O retained in soil
1	3.1840	1.6238	1.5602
2	3.1840	.7378	2.4462
3	3.1840	.4458	2.7382
4	3.1840	.7472	2.4368
5	3.1840	.5520	2.6320

An examination of the water extract of the soil treated with potassium chloride shows that the solubility of the acid radical is not affected by the soil. All the chloride appears in the solution as potassium chloride or as the acid radical of new salts. The new salts are chiefly chlorides of calcium, magnesium and sodium. If the acid radical is the sulphate or nitrate, the same conditions of solubility occur. A possible exception is the case where more calcium sulphate is formed than can dissolve in the given volume of water.

Salts of iron and aluminum must in some cases be formed in these reactions. Their rare appearance in the solution is probably due to alkalinity of the water extract which in many instances is sufficient to cause these salts to hydrolyze and the bases to reprecipitate.

Different conditions of solubility are observed in the case of the phosphates. The extent to which they are taken from solution and retained by the soil is shown in Table XI on page 19.

When soils react with potassium chloride, nitrate, and sulphate, the reaction must be chemical, because the amounts of new salts which appear in the water extract are equivalent to the amount of potassium removed. When soils react with potassium phosphate, both the base and acid radical are removed from solution.

TABLE XI

No. of Soil	Grams P_2O_5 as K_2HPO_4 per Kg. of soil	Total grams P_2O_5 recovered	Total grams P_2O_5 retained in the soil
1	2.4000	1.1985	1.2015
2	2.4000	.4806	1.9194
3	2.4000	.0846	2.3154
4	2.4000	.8355	1.5645
5	2.4000	.5553	1.8447

No new salts appear in solution and the water extract gives no evidence of the nature of the reaction. By analogy, however, the reaction must be chemical. When potassium exchanges places with calcium and magnesium, these in turn form phosphates which have a very low solubility and do not appear in the solution. This is further substantiated by the fact that, where large amounts of calcium sulphate are formed, not all of the acid radical appears in solution.

The data in Tables X and XI were obtained as in Table IX by adding to the soils di-potassium phosphate in solution and bringing the moisture content up to 20% by the addition of water. The samples were thoroughly mixed, placed in sealed jars, and allowed to stand for several weeks. They were then shaken with water and the amount of soluble potassium determined.

It has been shown in Table VIII that when potassium chloride is percolated through columns of soil, potassium is removed from solution and retained in the soil. The solubility of the soil potassium is therefore not increased by such a solution. A number of solutions of different salts were percolated through the soils to determine what effect they might have on the solubility of the soil potassium. For these experiments, solutions were made of sodium nitrate, sodium chloride, sodium carbonate, and commercial acid phosphate. The strength of these solutions was the same as that of the potassium chloride used in Table VII on the basis of the potassium equivalent. The amount of soil was also 500 grams. The data obtained from these experiments follow:

TABLE XII. SODIUM NITRATE SOLUTION

No. of Soil	Grams K_2O in first 300 cc. of percolate	Grams K_2O in third 300 cc. of percolate	Grams K_2O in fifth 300 cc. of percolate	Grams K_2O in seventh 300 cc. of percolate	Grams K_2O in ninth 300 cc. of percolate	Grams K_2O in eleventh 300 cc. of percolate	Grams K_2O in first 3600 cc. of percolate
1	.0029	.0036	.0015	.0007	.0005	.0003	.0190
2	.0027	.0036	.0013	.0006	.0007	.0002	.0182
3	.0032	.0023	.0020	.0011	.0006	.0004	.0192
4	.0039	.0037	.0025	.0016	.0014	.0007	.0276
5	.0051	.0046	.0024	.0018	.0012	.0006	.0314

TABLE XIII. SODIUM CHLORIDE SOLUTION

No. of Soil	Grams K_2O in first 300 cc. of percolate	Grams K_2O in third 300 cc. of percolate	Grams K_2O in fifth 300 cc. of percolate	Grams K_2O in seventh 300 cc. of percolate	Grams K_2O in ninth 300 cc. of percolate	Grams K_2O in eleventh 300 cc. of percolate	Grams K_2O in first 3600 cc. of percolate (Approx.)
1	.0021	.0017	.0010	.0004	.0005	.0003	.0120
2	.0017	.0022	.0010	.0005	.0003	.0004	.0122
3	.0024	.0024	.0009	.0008	.0002	.0004	.0142
4	.0025	.0026	.0018	.0006	.0008	.0006	.0178
5	.0042	.0037	.0015	.0017	.0008	.0010	.0258

TABLE XIV. SODIUM CARBONATE SOLUTION

No. of Soil	Grams K_2O in first 300 cc. of percolate	Grams K_2O in third 300 cc. of percolate	Grams K_2O in fifth 300 cc. of percolate	Grams K_2O in seventh 300 cc. of percolate	Grams K_2O in ninth 300 cc. of percolate	Grams K_2O in eleventh 300 cc. of percolate	Grams K_2O in first 3600 cc. of percolate
1	.0019	.0015	.0011	.0005	.0004	.0003	.0114
2	.0021	.0013	.0008	.0009	.0003	.0004	.0116
3	.0025	.0020	.0010	.0010	.0004	.0004	.0146
4	.0022	.0019	.0014	.0007	.0005	.0007	.0148
5	.0025	.0024	.0022	.0018	.0008	.0006	.0206

TABLE XV. ACID PHOSPHATE SOLUTION

No. of Soil	Grams K ₂ O in first 300 cc. of percolate	Grams K ₂ O in third 300 cc. of percolate	Grams K ₂ O in fifth 300 cc. of percolate	Grams K ₂ O in seventh 300 cc. of percolate	Grams K ₂ O in ninth 300 cc. of percolate	Grams K ₂ O in eleventh 300 cc. of percolate	Grams K ₂ O in first 3600 cc. of percolate (Approx.)
1	.0020	.0026	.0017	.0002	.0004	.0003	.0144
2	.0014	.0026	.0019	.0003	.0008	.0005	.0150
3	.0025	.0027	.0021	.0005	.0006	.0004	.0176
4	.0024	.0041	.0015	.0003	.0010	.0007	.0200
5	.0043	.0042	.0018	.0005	.0010	.0009	.0254

These data show that dilute solutions of sodium nitrate, sodium chloride, sodium carbonate, and acid phosphate, in contact with these soils, liberate potassium in considerable amounts. The data in Table XV was secured to determine the effect of commercial acid phosphate on the solubility of the soil potassium. A sample was found which contained no potassium, and the soluble phosphate extracted with water. The free acid was neutralized with lime, the solution filtered and standardized.

As already stated, these data could not be obtained from field work because of the relatively small amounts of fertilizer generally used. There is, however, no reason to believe that these same reactions do not take place under field conditions. The solutions used in these experiments, while dilute, are much more concentrated than soil solutions, excepting under special conditions. Nitrate of soda and acid phosphate solutions are very active in their effect on potassium. This has a very practical bearing in relation to crops grown in connection with nitrate and acid phosphate fertilizers. In order to determine the effect of calcium carbonate and calcium sulphate, these salts were mixed dry with the soil at the rate of 1 gram per 100 grams of soil. Distilled water was percolated through and the percolate examined for potassium.

The data in Table XVI as well as other observations made in this laboratory show that calcium oxide and calcium carbonate do not liberate potassium from these soils. Some observations have indicated a decreased solubility. A limited number

TABLE XVI

No. of Soil	Parts per million of potassium in first 300 cc. of percolate of distilled water through 500 grams soil	Parts per million of potassium in first 300 cc. of percolate of distilled water through 500 grams soil plus 1% calcium carbonate	Parts per million of potassium in first 300 cc. of percolate of distilled water through 500 grams soil plus 1% calcium sulfate
1	75	92	224
2	287	323	442
3	179	68	383
4	58	72	140
5	136	50	172

of experiments with calcium sulfate indicate that small amounts of potassium are made soluble. These determinations have been made colorimetrically.

It has been shown in a preceding table how the soil behaves toward potassium salts when applied as soluble fertilizer constituents. The amount of water-soluble potassium in many different samples of soil has been determined to show, if possible, whether there is any definite relation between the total potassium content of the soil and the amount of water-soluble potassium in the same soil. Such a relation has not been established with satisfactory assurance because it has not been possible to secure soils which differ only as regards the total potassium content.

The amount of potassium is usually in proportion to the amount of clay in the soil. The amount of clay has considerable effect on the nature of the organic matter. The amount and nature of organic matter apparently affects the solubility of potassium and other mineral constituents; also, some soils carry a large portion of their potassium in the form of minerals. This is particularly true of the sandy soils. The solubility of potassium in mineral form must be different from that in the form of clay. This must be true because of the influence of the clay itself. Also, the past treatment of the soil may influence the solubility of potassium, depending upon cultivation, and whether or not commercial fertilizers have been used.

The solubility of potassium in pure ground feldspar, for instance, is very different, depending on whether the solvent con-

sists of pure water, water-carrying calcium hydroxide, or such salts as sodium nitrate, calcium sulphate, etc., and whether the mineral is pure or mixed with clay. These facts are shown by data in the following tables:

TABLE XVII

Reagent added	Amt. of reagent added in grams	Cc. water	Amt. of K ₂ O liberated in grams	Average	Amt. of K ₂ O liberated by action of reagent
O	0	180	.0064	.0067	0
O	0	"	.0069		
O	0	"	.0070		
CaO	1	"	.0122	.0149	.0082
CaO	2	"	.0156		
CaO	2	"	.0168		
CaSO ₄	1	"	.0076	.0091	.0024
CaSO ₄	2	"	.0080		
CaSO ₄	3	"	.0118		
NaNO ₃	1	"	.0120	.0120	.0053
NaNO ₃	2	"	.0121		
(NH ₄) ₂ SO ₄	1	"	.0120	.0126	.0059
(NH ₄) ₂ SO ₄	2	"	.0132		
Na ₂ CO ₃	1	"	.0096	.0103	.0036
Na ₂ CO ₃	2	"	.0109		
Na ₂ HPO ₄	1	"	.0109	.0107	.0040
Na ₂ HPO ₄	2	"	.0087		

The above table shows the amount of potassium going into solution in a given volume of water upon stirring feldspar with some of the more common fertilizer constituents. Figures show-

ing the solubility of potassium when feldspar is stirred with clay and calcium oxide follow:

TABLE XVIII

Number	Grams feldspar	Grams clay	Grams CaO	Cc. water	Soluble K ₂ O in grams
1	0	25	0	180	.0014
2	0	25	2	180	.0011
3	30	25	1	180	.1172
4	30	25	2	180	.0062
5	30	0	0	180	.0067
6	30	0	0	180	.0072
7	30	0	1	180	.0151
8	30	0	2	180	.0158

The data in Table XVII and Table XVIII were obtained by placing the different combinations in a thermostat at room temperature and stirring until there was no further action.

These data show conditions which may be met with in soil studies and why it is difficult to eliminate them when making comparisons. The mineral feldspar has a certain solubility as regards potassium when the solvent is pure water. The addition of calcium oxide, sodium nitrate and other salts increases the solubility very greatly. The presence of clay decreases this effect. All soils, except the pure sands, contain some clay, therefore the solubility of the minerals in the soil is affected by the clay and is different from what would be expected from the pure mineral. At present, it is not known whether the clay decreases the action of the solvent or whether it removes the potassium from solution as rapidly as it dissolves. The latter seems the more probable.

In the field a number of plots have been under observation. These plots represent nearly all types of New Hampshire soils and were selected with care, particularly in regard to uniformity of soil and cultural conditions. These plots have been fertilized with nitrate of soda, acid phosphate, and sulphate or muriate of potash. Where used, nitrogen has been applied at the

rate of 40 lbs. per acre, phosphoric acid (P_2O_5) at the rate of 50 lbs. per acre, and potash (K_2O) at the rate of 120 lbs. per acre. These amounts are not to be recommended in practice but, for the purpose of determining effects, are very satisfactory. The fertilizers were applied as top dressing. Some of these plots have been under observation for seven years.

An examination of the soil from these plots in the laboratory shows that some of the fertilizer constituents disappear very rapidly after they are applied to the soil. It is not difficult to find the nitrate and ammonium salts for some time after they have been applied but for all practical purposes the potassium and phosphoric acid change from soluble forms soon after the first good rainfall and in an ordinary application cannot be found by chemical methods now in use. This is in keeping with the results obtained in the experiments which have already been discussed and which show the chemical reaction which takes place between soils and potassium salts. Like the sulfate and chloride, the nitrate radical remains soluble until it finally disappears through leaching or decomposition.

Data are tabulated in Table XIX which show the relative amounts of inorganic water-soluble soil constituents in a series of fertilized and unfertilized plots. The determinations were made some time after the fertilizers were applied and after a good rain had fallen. The data in Tables XIX and XX were obtained by extracting 100 grams of soil with 500 cc. of water for three minutes. After filtering through a Chamberlain porcelain filter, 100 cc. of the filtrate were evaporated to dryness, the organic matter driven off and the residue weighed.

Averages show that the plots fertilized carry a little more inorganic water soluble material than those which have not been fertilized. The relative amounts of soil and fertilizing elements are so different that no very satisfactory results can be had to determine the effect of the fertilizers on the soil constituents. Clay soils very readily take up practically all of the soluble fertilizer elements soon after they are applied.

The water-soluble inorganic matter from a series of plots on a light soil show the effect of the application of fertilizers. These plots are in an orchard and have been fertilized for seven years.

TABLE XIX

Water Soluble Inorganic Matter	
Unfertilized plots	Fertilized plots
.0016 grams	.0020 grams
.0017	.0038
.0022	.0018
.0020	.0031
.0020	.0015
.0026	.0015
.0030	.0027
.0015	.0029
.0017	.0029
.0016	.0023
.0022	.0021
.0017	.0020
.0017	.0018
.0016	.0018
.0015	.0027
	.0019
	.0017
	.0017
Average .0019	Average .0022

The soil is sandy with some gravel and carries but little clay in surface or subsoil. This soil contains relatively small amounts of organic matter and the conditions are very different from the clay soil already referred to.

Table XX shows the water-soluble inorganic constituents in the checks and the fertilized plots. The data show a higher amount of water-soluble inorganic matter where the fertilizers have been applied. The types of soil lying between this and the heavy clay soil will show a higher water-soluble inorganic content when fertilized. This will be greater as the soil becomes lighter in character.

TABLE XX

Water-Soluble Inorganic Matter			
Unfertilized plots		Fertilized plots	
	.0024		.0087
	.0041		.0086
	.0032		.0109
	.0037		.0108
	.0050		.0105
			.0098
			.0092
Average	.0037	Average	.0098

There has not been any definite relation between the amount of water-soluble material in the soil and the amount of crop produced on the light soil from which the data in Table XX was obtained. The increased amount of soluble material has not produced larger crops of apples nor better cover crops of crimson clover. The unfertilized plots show approximately only two-fifths as much water-soluble material as was found in the fertilized plots. Other conditions being the same, it would appear that beyond a certain point there is no advantage in having a large amount of water-soluble inorganic matter in the soil. From the data in Table XX and from other observations, it follows that the amount of water-soluble inorganic material in the plots which received no fertilizer is as much as can be used to any advantage. The additional amount found in the fertilized plots has not been used. In the observations on grass plots on light soils, where the amount of water-soluble inorganic material is increased by means of phosphoric acid and potassium salts, there is practically no increased production. The increased amount of water-soluble inorganic material resulting from their application is not of use to the plant. It is also true that any slight increase that potassium salts produce in the water-soluble inorganic material in the heavy clay soils is of no use to the plant. This must be proof

that the amount of water-soluble potash in these soils is not a limiting factor in production. These observations show that, after a certain concentration is reached in the soil solution, no advantage can be expected from a further concentration. Where the amount of water-soluble inorganic material is increased by means of nitrate of soda on the grass plots, an increase in yield is always effected. This increased yield is due to the fact that nitrogen has been supplied and that nitrogen is the first limiting factor in the growth of the plant. Field observations show that the grass plant is able to secure large quantities of potash from the soil and that the supply of potassium is not an early limiting factor in the production of hay. Peat soils, which are relatively high in organic matter, respond readily to applications of potassium fertilizers.

The data obtained on the effect of potassium fertilizers on the yield are tabulated in Table XXI. This table shows that potassium fertilizers used alone have not produced an appreciable increased yield on these soils. The difference between the potash plots and the check plots beside them are, on the average of the fifty-one plots, only thirty-six pounds per acre.

The data obtained in connection with nitrate of soda used alone and with potash are tabulated in Table XXII. From the data it is at once evident that when the yield is increased by the use of nitrogen the natural supply of potassium is still adequate. Further it does not appear that any satisfactory increased yield can be obtained in a practical way by supplying potash fertilizers in addition to nitrate of soda.

The average of the ninety-three observations given in Tables XXI and XXII in connection with the use of potash alone and with nitrogen shows very little increase in yield. The increase observed is too slight to be of any practical importance. In a few cases an increased yield has been produced. These increases, however, are slight and practically afford but little opportunity for profit.

The addition of phosphoric acid to potassium and nitrogen fertilizers may increase the yield. In most of these observations, the phosphoric acid accounts for this increase. The phosphoric acid problem and its relation to the production of hay will be dealt with in a subsequent paper.

TABLES XXI AND XXII

Yield in Tons per Acre				Yield in Tons per Acre			
No.	Check	Potash	Increase due to potash	No.	Check	Nitro- gen	Nitro- gen and potash
1	2.601	2.415	*	1	2.863	3.257	3.200
2	2.251	2.438	.187	2	1.808	2.601	2.409
3	1.158	1.226	.068	3	.868	1.227	1.403
4	1.547	1.725	.178	4	.793	1.318	1.265
5	1.135	1.139	.004	5	1.298	2.121	2.497
6	.735	.635	*	6	1.641	1.818	1.668
7	.749	.717	*	7	1.250	2.992	3.115
8	2.370	2.625	.255	8	1.750	2.250	2.250
9	.980	1.212	.242	9	.465	1.322	1.207
10	1.144	1.116	*	10	2.236	2.783	2.870
11	1.816	1.616	*	11	.350	.856	.910
12	1.680	1.570	*	12	2.047	3.080	2.905
13	1.988	2.252	.264	13	.980	2.012	1.890
14	1.888	2.005	.117	14	1.313	2.390	2.740
15	1.250	1.330	.080	15	.577	.858	.612
16	1.465	1.402	*	16	1.750	2.188	2.188
17	.862	.726	*	17	.875	2.100	1.750
18	1.198	1.253	.055	18	1.732	2.695	2.736
19	2.235	2.247	.012	19	1.750	2.850	2.975
20	.350	.385	.035	20	1.230	2.835	3.080
21	1.562	1.856	.294	21	1.505	2.640	2.922
22	1.313	1.348	.035	22	2.852	3.850	4.130
23	.577	.577	*	23	1.695	2.712	2.783
24	1.750	1.750	*	24	2.170	3.475	3.375
25	1.162	1.226	.064	25	1.750	3.175	3.300
26	1.244	1.180	*	26	1.032	2.026	2.102
27	1.732	1.662	*	27	1.575	2.730	2.432
28	1.750	1.837	.087	28	2.118	3.290	3.185
29	1.575	1.575	*	29	2.093	2.998	2.979
30	1.032	1.032	*	30	.805	2.135	2.135
31	1.505	1.578	.073	31	.665	1.030	1.198
32	1.335	1.226	*	32	1.365	2.415	2.678
33	1.271	1.334	.063	33	.791	1.829	1.730
34	1.138	.997	*	34	1.312	3.202	3.360
35	1.347	1.242	*	35	1.015	1.855	2.170
36	.805	.636	*	36	.615	1.925	2.257
37	.892	1.073	.181	37	.822	1.715	1.750
38	2.047	2.275	.228	38	.962	1.575	2.100
39	.465	.402	*	39	.858	1.855	1.417
40	.665	.630	*	40	.630	1.295	1.575
41	1.138	1.032	*	41	1.140	2.695	2.887
42	.791	.764	*	42	1.347	2.377	2.477
43	.823	.875	.052				
44	1.015	1.051	.036	Average	1.350	2.294	2.347
45	.062	.956	*				
46	.822	.840	.018				
47	1.760	1.750	*				
48	.858	.682	*				
49	.808	1.035	.227				
50	1.575	1.627	.052				
51	.630	.578	*				
Average	1.289	1.307	.018				

* Decreased yield.

Observations have been made on two clover crops to determine if the natural potassium supply would meet the requirements of this crop. Clover requires a considerably larger amount of potassium than does timothy. The following data shows the effect of the addition of potassium fertilizers on the potassium content of the crop.

TABLE XXIII

Per cent. K ₂ O in clover from check plots		Per cent. K ₂ O from plots treated with potash	
	2.93		2.56
	2.40		2.01
	1.66		2.89
	1.43		2.55
	2.02		2.10
			1.90
Average	2.08	Average	2.33

The following table shows the effect of nitrate of soda on the potassium content of the crop:

Per cent. K ₂ O in clover from check plots		Per cent. K ₂ O from plots treated with nitrogen	
	2.41		1.66
	1.49		1.79
	2.22		2.28
	1.56		2.16
Average	1.92	Average	1.97

The clover on the plots fertilized with nitrate of soda alone, and with potash alone, contained, on the average, a very little more potassium than the average amount found on the check plots. It has not been possible to secure enough data to determine the effect of potassium fertilizers on the yield of clover.

It appears, however, that the clover plant can secure enough potassium from the soil to produce a crop containing a normal amount of potassium.

From a practical standpoint, the use of potassium fertilizers on these soils, for the production of grass, cannot be recommended. At best and under the most favorable conditions, the most that can be expected is the return of a dollar for the one expended. Therefore the practice of top dressing grass land with potassium fertilizers cannot be expected to be profitable.

The foregoing data show that large yields have been obtained without the use of any potash in the fertilizers and that the composition of the crop is not materially changed by its use. It is evident that, under favorable conditions, the potassium which is in the soil is sufficiently soluble to supply the needs of the crop. Frequent and thorough cultivation, together with rotation of crops, tend to create favorable conditions. The use of nitrate of soda, sulfate of ammonia, acid phosphate, and acidulated fertilizers tends to increase the solubility of the soil potassium.

SUMMARY

1. New Hampshire soils are rich in potassium and are naturally adapted to the production of hay.
2. The natural soil potassium is present as clay and in mineral form.
3. The minerals have a definite solubility in water which is increased by the salts used in fertilizers.
4. Calcium carbonate and lime have practically no effect on the solubility of soil potassium.
5. When potassium phosphate reacts with the soil, no new soluble salts appear in solution.
6. When other potassium salts react with the soil, new bases appear in solution.
7. The solubility of the common acid radicals, excepting phosphoric, is not affected by the action of the soil.
8. The effect of sodium chloride, sodium nitrate, sodium carbonate and acid phosphate is to greatly increase the solubility of soil potassium.
9. The reaction between these salts and the soil is chemical.
10. Field data show that potassium fertilizers do not produce increased yields of hay, particularly on clay soils.
11. The composition of the hay plotted against the yield shows that when no potassium fertilizers are used, the soil supplies enough potassium for the growth of the crop.
12. From a practical point of view, the use of potassium fertilizers on these soils is unprofitable for the production of hay.



